UDC 666.3-13:666.762.12/.93/.862

MECHANICAL TREATMENT OF CERAMIC MATERIALS BASED ON ALUMINUM OXIDE, SILICON NITRIDE, AND SILICON CARBIDE

I. L. Shkarupa[1] and D. A. Klimov[1]

Translated from Steklo i Keramika, No. 6, pp. 16 – 18, June, 2004.

A comparative analysis of the mechanical treatment of ceramic materials based on aluminum oxide and silicon nitride and carbide is performed. Recommendations for the selection of the type of grinding wheel, the grinding velocity, and the pressure exerted by the wheel on a machined part are formulated.

Strong and hard ceramics of grades TSM-303, OTM-906, OTM-919, and OTM-923 that belong to the class of structural ceramics, as a rule, are used to produce articles with complex profiles; therefore, the problems of their machine treatment are topical. We have attempted to identify the dependences of the machinability of different ceramics on the type of grinding wheel, its cutting velocities, and the force of pressing the wheel to the product treated. The main physicomechanical properties of these materials are listed in Table 1.

TSM-303 is a high-alumina ceramic (97.6% Al_2O_3) produced by slip casting. The temperature of preliminary sintering is 1000°C, and the temperature of final sintering is 1550°C (in air). The linear shrinkage is 10.5%. Warping is insignificant. The production of preforms with a minimum tolerance for machine treatment is possible.

OTM-906 is hot-molded silicon nitride produced at a molding pressure of 20 MPa. The molding temperature is 1750°C. Only preforms of a simple shape with a considerable defect layer (2 mm across) can be produced; consequently, substantial mechanical treatment is required.

OTM-919 is sintered silicon nitride produced by slip casting. The preliminary sintering temperature is 350°C, and the final sintering temperature is 1950°C at a pressure of 1 MPa (in nitrogen). The linear shrinkage is 14.5%. Warping is significant. Preforms with admissible machine-treatment tolerances can be obtained.

OTM-923 is self-bonded silicon carbide produced by reaction impregnation (molding pressure 60 MPa at 20°C); the temperature of impregnation and reaction sintering is 2100°C (in argon). Preforms with admissible tolerances for machine treatment can be produced.

Ceramics products obtained using machine treatment are shown in Fig. 1.

The studies intended to select the optimum conditions for mechanical treatment of ceramics have been performed at the Diarim-AB Research-and Production Center together with the Tekhnologiya Research-and-Production Enterprise.

[1] Tekhnologiya Research-and-Development Enterprise (Federal State Company), Obninsk, Kaluga Region, Russia; Diarim-AB Research-and-Production Center, Moscow, Russia.

TABLE 1

Ceramic	Density, kg/m^3	Open porosity, %	Bending strength, MPa	Elasticity modulus, HPa	Microhardness, HPa	Destruction viscosity K_{1c}, MPa · m$^{1/2}$	Thermal conductivity W/(m · K)	TCLE, 10^{-6} K^{-1} in temperature interval 300 – 1200°C	Operating temperature, K	Linear shrinkage, %
TSM-303	3750	0	300	350	14,000	–	17	8.4	1400 – 1500	10.5
OTM-906	3300	0	600	300	16,000	6.0	18	3.7	1600	–
OTM-919	3230	0 – 1	545	290	12,000	5.7	10 – 15	3.6	1300 – 1400	14 – 15
OTM-923	3000 – 3100	0.2 – 1.0	180	–	12,000 – 27,000*	3.6	–	2.6 – 4.5**	1300 – 1400	–

* Different phases have different microhardness.

** In temperature interval 293 – 1173 K.

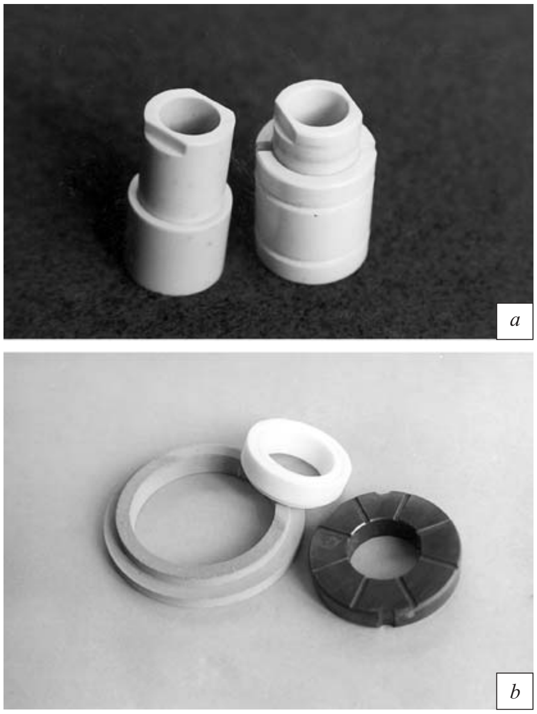

Fig. 1. Bearing (*a*) and friction units (*b*).

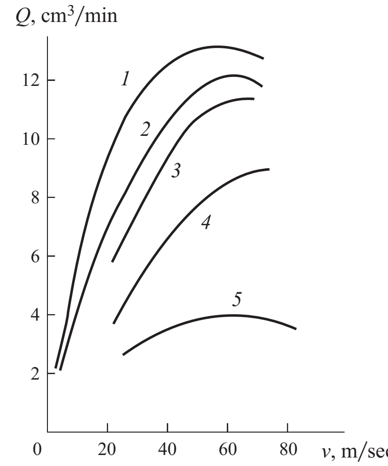

Fig. 2. Dependence of efficiency Q on the grinding velocity v of hot-molded silicon nitride with pressing force of 70 N: *1*) AS6 wheel, grain size 80/63, diamond content 100%, M04 binder; *2*) AS6 wheel, grain size 125/100, diamond content 100%, M04 binder; *3*) wheel AS6, grain size 80/63, diamond content 150%, M04 binder; *4*) AS6 wheel, grain size 80/63, diamond content 100%, M1 binder; *5*) ASM wheel, grain size 40/28, diamond content 100%, M04 binder.

Most of the experiments were implemented in flat grinding of samples of size 7 × 7 × 70 mm on a ZL741VF-10 machine by varying the type of binder of the grain wheel, the grain size, and the concentration of diamonds in the wheel.

Let us introduce a parameter called the "grinding coefficient," which is understood as the ratio of the volume of material removed to the consumed volume of the abrasive wheel. The grinding coefficients of ceramics depending on the materials treated and the diamond wheel parameters are shown in Table 2 (the grinding velocity was 32 m/sec).

The efficiency is minimum in grinding ceramics OTM-906 and maximum in grinding ceramic OTM-923.

TABLE 2

Grinding coefficients of ceramics				Grinding wheel parameters		
TSM-303	OTM-906	OTM-919	OTM-923	diamond grade and binder	grain size	diamond content, %
190	80	130	420	AS15,	100/80	100
160	70	120	330	M04	80/63	100
170	50	105	300		100/80	50
130	–	93	240		80/63	50
178	80	110	260	AS6,	100/80	100
146	65	98	140	M1-02	80/63	100
125	45	82	130		100/80	50
95	–	79	85		80/63	50
160	65	110	300	AS4, M2-01	100/80	100
80	–	70	145		80/63	100

The grinding coefficient decreases with decreasing diamond content and diamond grain size. The grinding coefficient varies most significantly in treating silicon carbide (from 85 to 420) and least of all in treating hot-pressed silicon nitride (from 45 to 80).

The cutting capacity of a diamond wheel decreases with time. Immediately after dressing the grinding efficiency is maximum, and 0.5 – 3 min later it decreases significantly. The most perceptible (2 – 3 times) drop in the cutting capacity of the instrument was observed after the first 20 – 40 sec of grinding. A more detailed study of efficiency in flat grinding was carried out on ceramic plates made of hot-molded silicon nitride using diamond wheels on metallic binders (Fig. 2). The highest efficiency (13.2 cm^3/min) was reached with a grinding velocity of 55 m/sec on the AS6 wheel with grain size 80/63 and diamond content 100% on M04 binder. The lowest efficiency was observed using the ASM wheel with grain size 40/28, diamond content 100%, and M04 binder.

In the beginning of grinding the most protruding and, accordingly, the most loaded grain, was torn off from the binder, destroyed, and crumbled. At that period the grinding efficiency and the height of the surface irregularities are maximum. After the initial period the grinding process proceeds with a slowly declining efficiency, regardless of the method of dressing the wheel.

In machining ceramics, brittle destruction of abrasive grains prevails. The grains weakly bonded by the binder are torn off, the wheel relief is leveled, and a significantly higher number of grains are involved in the operation. As a higher number of grains come into contact with the material treated,

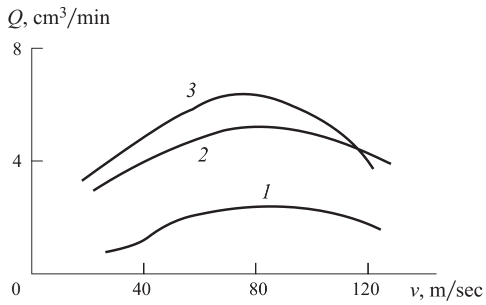

Fig. 3. Dependence of grinding efficiency Q of ceramics based on aluminum oxide on the cutting velocity v and pressure on the surface of ceramic pieces: *1*, *2*, and *3*) 1×10^5, 3×10^5, and 5×10^5 Pa, respectively.

the total stress level of the grinding process increases. In grinding ceramics for a long time, the radial component of the cutting force grows significantly. Thus, after treating ceramic OTM-906 for 15 min with a diamond wheel, the radial component of the cutting force grows on the average 2 – 3 times, and for ceramic OTM-919 it grows 1.8 – 2.5 times.

It can be seen in Fig. 3 that as the pressure exerted by the diamond wheel on the surface of a piece made of aluminum oxide grows from 0.1 to 0.5 MPa, the efficiency grows from 2.0 to 6.2 cm^3/min.

In grinding ceramics with microhardness up to 15,000 MPa the efficiency is maximum when the pressure of the diamond wheel is equal to 0.5 MPa. For ceramics with microhardness ranging from 15,000 to 27,000 MPa the maximum efficiency of the diamond wheel is reached at a pressure of 2.0 – 3.5 MPa. On further growth of the pressure the efficiency does not grow.

The use of the diamond wheel with optimum parameters makes it possible to significantly increase the efficiency. The efficiency of treating nitride ceramics grows to a maximum extent as the grain size of the wheel increases from 40/28 to 80/63. A further increase in the grain size up to 125/100 increases the efficiency less intensely, moreover, the quality of the polished surface perceptibly deteriorates. Furthermore, use of diamond wheels with grain sizes more than 100/80 leads to the formation of chips at their edges.

To reach the maximum grinding efficiency in the treatment of the specified materials, it is recommended to use the AS15 grinding wheel with grain size of 100/80 and diamond concentration 100% on the M04 binder.